FI-276

Selenium Accounting in the Grasslands Basin

Submitted by

United States Bureau of Reclamation
South-Central Area Office
2666 North Grove Industrial Drive
Fresno, California 94720

In cooperation with

San Luis and Delta Mendota Water Authority
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Grassland Water District
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Los Banos, California 93635

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July 28, 1997

I. Executive Summary

a1. Project Title: Selenium Accounting in the Grasslands Basin

a2. Applicants' Names:
Mike Delamore, United States Bureau of Reclamation, South-Central Area Office, Fresno, CA
Sally Benson, E. O. Lawrence Berkeley National Laboratory, Berkeley, CA
Joseph McGahan, San Luis and Delta Mendota Water Authority, Byron, CA
Don Marciochi, Grassland Water District, Los Banos, CA

b. Project Description: The objective of this project is to improve water quality and protect aquatic ecosystems from potentially harmful exposure to pollutants derived from agricultural drainage, specifically selenium. The specific project goals to meet this objective are:

1) To obtain a more accurate accounting of the selenium sources, transport, and storage in the Grasslands Basin;
2) To use this information to ensure that the water quality goals for water deliveries to the wetlands in the Grassland Water District can be met; and
3) To provide information that can be used to develop and implement improved options for reduction of selenium in drainwater through on-farm and district management practices.

Addressing these issues is important because the San Joaquin River is a major contributor of selenium to the Delta and San Francisco Bay. The majority of the selenium entering the San Joaquin River is derived from agricultural return flows from the Grasslands Basin. Reducing selenium in drainwater can be achieved by optimizing the effectiveness of drainwater management practices and thereby minimizing downstream impacts to fisheries and wildlife. The information obtained from this project is essential to successful selenium reduction.

The Grasslands Basin, located on the west side of the San Joaquin Valley, contains some of the world's most productive agricultural land and one of the most important waterfowl habitats on the Pacific Flyway. Both of these important natural resources require large volumes of high-quality water—water for irrigation of agricultural crops and water for creating seasonal and permanent wetlands. Each also requires drainage to remove some fraction of the water that is applied. Water delivery to and drainage from the Grasslands requires a complex network of canals. In the past, canals often had a dual purpose of fresh water delivery and drainage disposal. These complicated water operations compromised the canals' ability to fully deliver good quality water to the wetlands.

In 1996 the Grasslands Bypass Channel Project (GBCP) was initiated to alleviate this problem by consolidating the discharge of subsurface agricultural drainage water from 90,000 acres in the Grasslands Basin. The GBCP diverted drainwater from 90 miles of canals that provide water to nearly 100,00 acres of wetlands. To accomplish this, the GBCP provides a 2-year (possibly extended an additional 3 years) interim agreement to use a 28-mile section of the San Luis Drain to convey subsurface agricultural drainwater to the San Joaquin River. The agricultural drainwater contains high concentrations of selenium, nitrate and other trace elements that could adversely impact fisheries and waterfowl in the Grasslands, the Delta and San Francisco Bay. Therefore, as part of the GBCP, the agricultural drainers have agreed to reduce the amount of selenium being discharged into the San Joaquin River. To help the Grassland Area Drainers and Grassland Water District meet or exceed the water quality goals and reduce selenium loads we propose to provide better information about the sources and behavior of selenium in the Grasslands.

c. Approach/Tasks/Schedule: Our approach to achieving the project objective and goals is to 1) obtain a better understanding of selenium sources, transport, and storage in the Grasslands Basin; 2) understand how these are affected by drainwater management practices; and 3) transfer this knowledge to the drainwater managers and farm workers. The tasks and schedule for these activities are as follows:

Task 1. Identify and measure unknown or unquantified sources of selenium in the project area;

Task 2. Quantify losses or additions of selenium associated with conveyance and storage of drainwater; and
Task 3. Provide technology transfer and assistance to develop and implement improved options for reduction of selenium in drainwater through on-farm and district management practices.
This project will be completed by December 1999.

d. Justification for the Project and Funding by CALFED

The primary stressors addressed by this project are contaminants, particularly selenium, that enter the Grassland area wetlands and the lower San Joaquin River. Seasonal wetland and aquatic ecosystems in the Grasslands Basin and the San Joaquin River will benefit from better understanding and reduction of contaminant inputs to these habitats. Species that would directly or indirectly benefit from reduced contaminant loads include San Joaquin fall run Chinook salmon and migratory waterfowl. This project would supplement and complement ongoing and planned actions and programs to reduce selenium inputs to the Grassland wetlands and the San Joaquin River. One such program, the Grassland Bypass Channel Project, bypasses agricultural drainage water around wetland supply channels and requires steady reduction of selenium discharges to the San Joaquin River. This project will contribute to reduced contaminant loads to the Grassland wetlands and the San Joaquin River by identifying and quantifying selenium inputs from sources other than the agricultural area using the Bypass, and by providing information that will assist the Drainers to identify effective measures to reduce the selenium in their discharges.

e. Budget: 2 Year budget total of $1,302 K: Task 1. $228 K, Task 2. $750 K, Task 3. $324 K

f. Applicant Qualifications: The team submitting this proposal has extensive experience working on agricultural drainage and selenium related issues in the San Joaquin Valley and San Francisco Bay. Key personnel are assembled from the U. S. Bureau of Reclamation, E. O. Lawrence Berkeley National Laboratory, the San Luis and Delta Mendota Water Authority, and the Grassland Water District. Mike Delamore is currently the Chief of the USBR's San Joaquin Drainage Program, Joe McGahan is the Interim Drainage Coordinator for the San Luis and Delta Mendota Water Authority, Don Marciochi is the General Manager for the Grassland Water District and Dr. Sally Benson is the Earth Sciences Division Director at E. O. Lawrence Berkeley National Laboratory. Together they have over 50 years of experience on water supply, drainage and selenium issues in California.

g. Monitoring and Evaluation Data: This project will use a combination of existing data collected by the GBCP Interagency Compliance Monitoring Program and new data collected by the project investigators. All water quality measurements will be made in an EPA-certified laboratory under a well-established and documented quality assurance program. Peer review will be accomplished by twice yearly technical review and publication of project findings in peer-reviewed journals.

h. Local Support/Coordination with Other Programs/Compatibility with CALFED

Coordination with Other Programs	Local Support	Compatibility with CALFED Objectives
This program will be coordinated with the Interagency Compliance Monitoring Program supported by the USBR, USGS, USFWS, the Grassland Bypass Project Drainers, the Department of Water Resources, US EPA, and the Central Valley Regional Water Quality Control Board.	Panoche Drainage District Broadview Water District Firebaugh Canal Water District Camp 13 Drainage District Pacheco Water District Charleston Drainage District Grassland Water District	The objective of this project is to improve water quality and protect aquatic ecosystems from potentially harmful exposure to pollutants derived from agricultural drainage.

II. Title Page

a. Project Title: Selenium Accounting in the Grasslands Basin

b. Names of Applicants

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c. Type of Organization and Tax Status: Federal Agency

d. Tax identification Number: N/A

e. Technical and Financial Contact Person

Technical	Financial
Mike Delamore United States Bureau of Reclamation South-Central Area Office, Fresno 2666 North Grove Industrial Drive Fresno, California 94720 e-mail: mdelamore@mp.usbr.gov	Mike Delamore United States Bureau of Reclamation South-Central Area Office, Fresno 2666 North Grove Industrial Drive Fresno, California 94720 e-mail: mdelamore@mp.usbr.gov

f. Participants/Collaborators in Implementation

Federal Agencies	Local Irrigators and Drainers	State Agencies
U.S. Bureau of Reclamation U.S. Geological Survey	Panoche Drainage District Broadview Water District Firebaugh Canal Water District Camp 13 Drainage Area Pacheco Water District Charleston Drainage District Grassland Water District	• Central Valley Regional Water Quality Control Board • Department of Water Resources

g. RFP Project Type: Other Services

III. Project Description

a. Project Description and Approach

The objective of this project is to improve water quality and protect aquatic ecosystems from potentially harmful exposure to pollutants derived from agricultural drainage, specifically selenium. The specific project goals to meet this objective are:

1) To obtain a more accurate accounting of the selenium sources, transport, and storage in the Grasslands Basin;
2) To use this information to ensure that the water quality goals for water deliveries to the wetlands in the Grassland Water District can be met; and
3) To provide information that can be used to develop and implement improved options for reduction of selenium in drainwater through on-farm and district management practices.

Addressing these issues is important because the San Joaquin River is a major contributor of selenium to the Delta and San Francisco Bay. The majority of the selenium entering the San Joaquin River is derived from agricultural return flows from the Grasslands Basin. Reducing selenium in drainwater can be achieved by optimizing the effectiveness of drainwater management practices and thereby minimizing downstream impacts to fisheries and wildlife. The information obtained from this project is essential to successful selenium reduction. Reducing selenium in drainwater will be achieved by optimizing the effectiveness of drain water management practices within Grasslands and thereby minimizing downstream impacts to fisheries and wildlife.

The Grasslands Basin, located on the west side of the San Joaquin Valley, contains some of the world's most productive agricultural land and one of the most important habitats on the Pacific Flyway. Both of these important natural resources require large volumes of high-quality water—water for irrigation of agricultural crops and water for creating seasonal and permanent wetlands. Each also requires drainage to remove some fraction of the applied water. Water delivery to and drainage from the Grasslands requires a complex network of canals. In the past, canals often had a dual purpose of fresh water delivery and drainage disposal. Drainage water was also used to augment fresh water supplies to wetlands. When high concentrations of selenium were found in subsurface drainage from farms in the Grasslands in the mid-1980s, all drainage water deliveries to wetlands ceased. However, the canals continued to be used for both fresh water deliveries and drainage water disposal. These complicated water operations compromised the District's ability to fully deliver good quality water to the wetlands.

In 1996 the Grasslands Bypass Project (GBCP) was initiated to alleviate this problem by consolidating the discharge of subsurface agricultural drainage water from 90,000 acres in the Grasslands Basin. The GBCP diverted drainwater from 90 miles of canals that provide water to nearly 100,00 acres of wetlands. To accomplish this, the GBCP provides a 2-year (possibly extended an additional 3 years) interim agreement to use a 28-mile section of the San Luis Drain to convey subsurface agricultural drainwater to the San Joaquin River. The agricultural drainwater contains high concentrations of selenium, nitrate and other trace elements that could adversely impact fisheries and waterfowl in the Grasslands, the Delta and San Francisco Bay. Therefore, as part of the GBCP, the agricultural drainers have agreed to reduce the amount of selenium being discharged into the San Joaquin River.

To help the Grassland Area Drainers and Grassland Water District meet or exceed the water quality goals and reduce selenium loads, we propose to provide better information about the sources and behavior of selenium in the Grasslands. Our approach is to 1) obtain a better understanding of selenium sources, transport, and storage in the Grasslands Basin; 2) understand how these are affected by drainwater management practices; and 3) transfer this knowledge to the district drainwater managers and farm workers. Below are the specific tasks we propose to carry out. These tasks will take place concurrently and be completed within two years of the inception of the project.

Task 1. Identify and measure unknown or unquantified sources of selenium in the Grasslands

The GBCP has diverted high selenium subsurface agricultural drainage water from approximately 90 miles of wetland channels so as to allow the unimpaired diversion of fresh water to duck clubs and refuges in the Grasslands Basin. However, routine monitoring of Grasslands Basin channels conducted by the Grassland Water District and the Central Valley Regional Water Quality Control Board has occasionally revealed elevated concentrations of selenium in these channels (above the 2 ppb requirement for application to wetlands). Potential sources of this selenium include:

1. Wetland supply source water (Delta Mendota Canal) may occasionally contain selenium concentrations over 2 ppb;
2. Selenium sources from the area currently not incorporated into a federal water district or exchange contract district;
3. Mobilization of selenium from sediments, detritus, or algal biomass within a water conveyance channel;
4. Leakage through gates or control structures that should separate agricultural drainage and fresh water supplies; and
5. Transport of selenium into the Project area during heavy rainfall or flood events.

The purpose of Task 1 is to (1) identify and quantify the sources of selenium input into Grassland water supply canals; and (2) quantify the amount of selenium entering the Grasslands system from external sources during heavy rainfall or flood events. Below are the tasks that will be done to obtain this information.

Task 1a. Assemble and evaluate existing data and information related to water quality in the Grasslands Water District. A large volume of water quality data has been collected by various agencies and entities to determine the quality of water entering the wetlands and verify that selenium concentrations are less than the required 2 ppb. We will assemble the water quality data collected from these sources and identify the timing and frequency of locations where elevated selenium concentrations have been observed. From this evaluation we will identify the likely sources of selenium, establish their relative importance, and design a measurement program to locate and quantify them.

Task 1b. Obtain measurements to locate and verify potential sources of selenium entering the Grassland Water District. Based on the measurement program described above we will collect water quality samples and, if necessary, sediment samples to verify and quantify sources of selenium. Data collected will be evaluated with the Water Managers to determine its significance and to determine what, if any, further actions should be taken.

Task 1c. Design and implement a first-response plan to measure the amount of selenium entering and flowing through the Grasslands Basin during flood or heavy rainfall events. A first-response plan will be designed and implemented to measure the selenium entering and flowing through the Grasslands during heavy rainfall or flood events. Measurements will include water quality, suspended sediments, bed load sediments and flow. If significant erosion or deposition occurs in the canals or Sloughs this will be documented in an attempt to quantify selenium transport associated with these sediments. Data collected will be evaluated with the Water Managers to determine its significance and to determine what, if any, further actions should be taken.

Task 2. Quantify losses or additions of selenium associated with conveyance and storage of drainwater

Collection and disposal of subsurface drainwater in the Grasslands Basin are accomplished through the complex network of sumps, canals, the San Luis Drain, and Mud Slough shown in Map 1b. The agricultural fields are underlain by a pattern of subsurface pipes (tile drains) that discharge by gravity flow into a sump. Drainwater is then either stored in the sump, blended with

higher quality water for reuse, or transported into a canal for disposal into the San Joaquin River via the Grasslands Bypass. In some cases, water from the tile drains is prevented from freely flowing into the sumps, thereby leading to in-field (or subsurface) storage of drainwater. In this way, drainage from the field is controlled and release can be timed to meet selenium or salinity load requirements. Because of the chemical characteristics of selenium, each of the steps involved in managing and disposing of drainwater may lead to increases or decreases in the amount of selenium dissolved in the drainwater (Tokunaga and Benson, 1992; Quinn et al. , 1994). For example, earlier studies have shown that as much as 25% of the selenium entering the agricultural drainage canals and wetlands may have been removed from the drainwater in transit to the San Joaquin River.

Processes that are responsible for selenium removal are illustrated in Figure 1. They include uptake by algae, adsorption onto suspended solids, bacterial transformation to elemental selenium, and microbial and plant volatilization. With the exception of volatilization, which results in transport of selenium as dimethyl selenide to the atmosphere, all of the other processes lead to the accumulation of selenium in the sediments. The sediments may become a permanent repository for selenium, or the sediment-associated selenium may be recycled back into the water column and food web. Understanding the magnitude of these losses and the potential for recycling back into the ecosystem is important to a full accounting of the mass-balance for the Grasslands Basin. Moreover, understanding which management practices lead to removal and long-term sequestration can be an important component of optimizing drainwater management in the Grasslands Basin. Conversely, avoiding management practices that lead to recycling of selenium back into the food-web and water column will also assist the agricultural drainers reduce selenium loads.

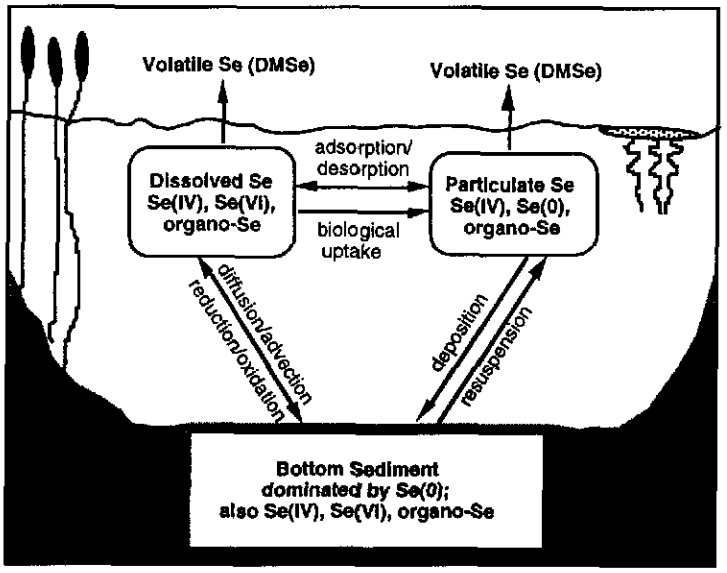


Figure 1. Major features of the selenium cycle in canals, the San Luis Drain, and Mud Slough.

Three specific subtasks will be undertaken to quantify the magnitude of selenium losses or additions associated with drainwater management. These are:

Task 2a. Quantify losses or additions of selenium that occur while drainwater is transported through the drainage canals, the San Luis Drain, and Mud Slough. A combination of measurements made using water quality samples, tracer tests, vegetation samples, sediment traps, turbidity meters, piezometers, sediment samples, and *in-situ* microcosms will be used to quantify the magnitude of the losses/additions of selenium that occur while drainwater is transported. The meas-

urements will be made periodically, as well as in response to events such as pre-irrigation, floods, heavy rains, and episodes when the canals have dried out. These measurements will be synthesized and interpreted with a mass balance model that accounts for selenium exchange between the water column, vegetation, and sediments.

Task 2b. Quantify losses/additions of selenium associated with surface storage of drainwater. A combination of measurements made using water quality samples, tracer tests, vegetation samples, sediment traps, turbidity meters, piezometers, sediment samples, and *in-situ* microcosms will be used to quantify the magnitude of the losses/additions of selenium that occur while water is stored in sumps and storage basins. The measurements will be made to track the selenium mass balance as a function of holding time. Measurements will be made during pre-irrigation, the irrigation season and, if possible, during the winter to determine the influence of temperature and other water quality parameters on rates of selenium removal. These measurements will be synthesized and interpreted with a mass balance model that accounts for selenium exchange between the water column, vegetation, and sediments.

Task 2c. Quantify losses/additions of selenium associated with in-field storage of drainwater. As described at the beginning of this section, the Grasslands Drainers have installed a number of DOS-IR type valves that prevent drainwater from freely flowing into the sumps, thereby leading to in-field (or subsurface) storage of drainwater. This in-field storage has the potential to decrease selenium concentrations in the drainwater due to microbially mediated transformation of selenate (the form of selenium found in drainwater) to elemental selenium (which precipitates from solution) during the time that the water is stored in the field. At present, the extent to which this could occur under the conditions associated with in-field storage is unknown. However, similar processes are well documented in the Central Valley both at Kesterson (Benson et al, 1991; and White et al, 1991) and in the Grasslands Drainage Basin (White and Dubrovsky, 1994). This task will use a combination of groundwater monitoring wells, vadose zone water samplers, and tracer tests to quantify the extent to which in-field storage can be used to reduce the selenium concentration in drainage before it is drained from the fields. Key variables will include the characteristics of the sediments (e.g., Sierran vs. Coast Range origin), the concentration of nitrate, depth of the water table, and depth of the drains (Benson, 1997). Data from this activity will be interpreted with a combination of selenium mass balance and groundwater flow models.

Task 3. Provide technology transfer and assistance to develop and implement improved options for reduction of selenium in drainwater through on-farm and district management practices.

The objective of this project is to improve water quality and protect aquatic ecosystems from potentially harmful exposure to pollutants derived from agricultural drainage, specifically selenium. To accomplish this objective we must transfer what we have learned about selenium sources, conveyance, and storage to the district drainage managers. We expect that information gained from Tasks 1 and 2 will identify improved options for on-farm and district drainwater management to help the Grasslands Area Drainers meet their selenium load and water quality goals. Below are tasks to assist the district drainage managers identify and develop practical options for on-farm and district drainwater management for reduction of selenium.

Task 3a. Assist the district drainage managers in developing tools and a catalog of practical on-farm and district drainwater management options that are helpful in reducing selenium loads in drainwater. A set of practical procedures and tools for reducing selenium loads and concentration in subsurface drainwater will be developed in cooperation with the district managers. Examples of the types of tools that will be developed could include charts showing selenium load reduction as a function of holding time for surface water storage and selenium load reduction as a function of in-field storage time. Procedures for enhancing selenium load reduction, such as not discouraging growth of algae or adding small amounts of agricultural waste products (leaf and stems) to the

drainage canals of holding ponds, will be identified. The effectiveness of each of these options will be determined and documented. An on-line catalogue of these options will be developed and made available to the district managers and farmers. On-farm workshops will be held by the district managers to transfer this knowledge broadly to the agricultural community.

Task 3b. Provide technical assistance in the implementation and evaluation of new or improved drainwater management options to reduce selenium levels in drainwater. As requested by the district managers and farmers, we will provide technical assistance in the implementation and evaluation of the site-specific actions that are taken to reduce selenium loads in drainwater. Case studies documenting the effectiveness of site-specific actions and lessons learned from each of these will be provided in the on-line catalogue of options described above.

b. Location of the Project

This project is located on the west side of the Central Valley, CA (see Map 1a). It encompasses nearly 100,000 acres of wetlands in the Grasslands Basin and the agricultural lands, drainwater canals, and water delivery canals within the Panoche Drainage District, Broadview Water District, Firebaugh Canal Water District, Camp 13 Drainage District, Pacheco Water District, and Charleston Drainage District. It also includes the 28 miles of the San Luis Drain that are north of the Grasslands Bypass and the 6 mile stretch of Mud Slough between the end of the San Luis Drain and the confluence with the San Joaquin River.

c. Expected Benefits

The primary stressors addressed by this project are contaminants, particularly selenium, that enter the Grassland area wetlands and the lower San Joaquin River. The San Joaquin River is a major contributor of selenium to the Delta and San Francisco Bay. The majority of the selenium entering the San Joaquin River is derived from agricultural return flows from the Grasslands Basin. Seasonal wetland and aquatic habitats in the Grassland basin and the San Joaquin River will benefit from better understanding and reduction of contaminant inputs to these habitats. Species that would directly or indirectly benefit from reduced contaminant loads include San Joaquin fall run Chinook salmon and migratory waterfowl. This project would supplement and complement ongoing and planned actions and programs to reduce selenium inputs to the Grassland wetlands and the San Joaquin River. One such program, the Grassland Bypass Channel Project, bypasses agricultural drainage water around wetland supply channels and requires steady reduction of selenium discharges to the San Joaquin River. This project will contribute to reduced contaminant loads to the Grassland wetlands and the San Joaquin River by identifying and quantifying selenium inputs from sources other than the agricultural area using the Bypass, and by providing information that will assist the Drainers to identify effective measures to reduce the selenium in their discharges.

d. Background and Technical Justification

A significant source of selenium input to the San Francisco Bay-Delta system comes from the San Joaquin River, and a large portion of this source originates in the Grasslands Basin. The Grasslands Bypass Channel Project is a first major step that has segregated high selenium discharges from good quality water entering wetlands within the Grasslands Basin, and is expected to lead to significant reductions in the quantity of selenium that is discharged to the San Joaquin River. Excellent cooperation among the individual growers and the Districts has already enabled enhanced management to control discharges and reduce potential impacts associated with drainage water. The locations of a number of these specific actions are illustrated by the symbols shown in Map 1b (e.g. farmer recirculation, DOS-IR type valves and District recirculation). However, better understanding of selenium sources and dynamics, and development of effective selenium reduc-

tion and management tools will be needed to meet CALFED water quality and contaminant reduction objectives.

Funding of this project is needed to supplement and complement other ongoing efforts and needed to reduce contaminant loads in CALFED priority habitats and species. This project will contribute to CALFED objectives by providing a more thorough accounting of selenium sources and a better understanding of the effects of drainwater management on selenium loads. In partnership with Water and Drainage District managers, this information will be used to develop and implement better and more effective selenium load reduction and drainwater management actions.

e. Proposed Scope of Work

Specific tasks and deliverables are indicated below and described in greater detail in Section IIIa. All tasks will take place concurrently and will be completed within two years from the inception of the project. Quarterly reports describing progress and financial expenditures will be provided throughout the duration of the project.

Tasks	Deliverables
Task 1. Identify and measure unknown or unquantified sources of selenium in the Grasslands.	1. Quarterly status reports. 2. Final report identifying and quantifying additional sources of selenium.
Task 2. Quantify losses or additions of selenium during conveyance and storage of drainwater.	1. Quarterly status reports. 2. Final report quantifying selenium losses or additions during conveyance and storage.
Task 3. Provide technology transfer and assistance to develop and implement improved options for reduction of selenium in drainwater through on-farm and district management practices.	1. On-line catalog of practical options for reducing selenium in drainwater. 2. Demonstration projects. 3. Technical assistance. 4. Case studies.

f. Monitoring and Data Evaluation

This project will use a combination of existing data collected by the Interagency Compliance Monitoring Program for the Grasslands Bypass Project and new data collected by the project investigators. All water quality measurements will be made in an EPA certified laboratory under an established and documented quality assurance program. Peer review will be accomplished in 2 ways. We will establish a technical review committee composed of staff members from the U.S. Geological Survey, U.S. Fish and Wildlife, the University of California and the Water Quality Control Board. Twice yearly informal workshops will be held to peer review the data and analysis generated by the project. Participants in related projects will be invited to the workshops to share information and approaches. Technical findings will also be published in peer-reviewed journals.

g. Implementability

The Grasslands Bypass Channel Project has already received interim permission for use of the San Luis Drain for a two year period, with a possible 3-year extension. An Environmental Impact Statement (EIS) will be required to extend use past this 5-year period. Data gathered as part of this project will broaden the range of alternatives that can be considered by the EIS and improve the knowledge underpinning the recommended action.

The close cooperation among the Water District, Drainage Districts and the USBR represented by the collaborative nature of this proposal is indicative of the willingness of these parties to work together to find solutions to these challenging issues.

Reference Table

Benson, S. M., 1997 in press, Influence of Nitrate on the Mobility and Reduction Kinetics of Selenium in Groundwater Systems, in Environmental Chemistry of Selenium, W.T. Frankenberger and R.A. Engberg, editors, Marcel Dekker, New York.

Benson, S.M., A.F. White, S. Halfman, S. Flexser, and M. Alavi. 1991. Groundwater contamination at Kesterson Reservoir, California 1. Hydrogeologic setting and conservative solute transport. Water Resources. Res. 27:1071-1084.

Tokunaga, T.K., and S.M. Benson. 1992. Selenium in Kesterson Reservoir ephemeral pools formed by groundwater rise: 1. Field studies. J. Environ. Qual. 21:246-251.

Quinn, N, T. Tokunaga, J. Cylde and R. Salve, Investigation of Selenium Losses in Canals Used for Conveyance of Sub-Surface Drainage in the San Joaquin Valley, California. Proceeding of the International Conference on Groundwater Ecology, Atlanta, GA.

White, A.F., S.M. Benson, A.W. Yee, H.A. Wollenberg, and S. Flexser. 1991. Groundwater contamination at Kesterson Reservoir, California, Part 2. Geochemical parameters influencing selenium mobility. Water Resources. Res. 27:1085-1098.

White, A.F. and N. M. Dubrovsky, 1994. Chemical Oxidation-Reduction Controls on Selenium Mobility in Groundwater Systems, in Selenium in the Environment, Frankenberger and Benson, editors, Marcel Dekker, New York.

IV. COSTS AND SCHEDULE TO IMPLEMENT THE PROPOSED PROJECT

a. Budget Costs

The USBR will provide technical and contract management for the project. The total budget over the 2 year period is provided in Table 1. The work will be performed by a combination of personnel from the USBR, the E. O. Lawrence Berkeley National Laboratory (LBNL), the Grassland Water District, and the San Luis and Delta Mendota Water Authority. If additional expertise is needed, such as that provided by scientists from the U. S. Geological Survey, the University of California, or the U. S. Fish and Wildlife Service, their services will be sought. The expected distribution of funds amongst the current participants is as follows. However, as the project is implemented, resources may shift to accommodate project needs.

Task	Direct Labor Hours	Direct Salary and Benefits	Overhead Labor	Service Contracts	Material and Acquisition Contracts	Misc. and Other Direct Costs	Total Cost
Task 1	4,315	$164,400	$14,200	$30,000	$7,000	$12,600	$228,200
Task 2	8,822	$348,100	$338,100	$35,000	$18,000	$10,800	$750,000
Task 3	4,089	$161,900	$112,600	$35,000	$2,000	$12,500	$324,000
Total	17,726	$674,400	$464,900	$100,000	$27,000	$35,900	$1,302,200

Table 1. Budget for project broken down by task.

Task	USBR	LBNL	Grassland Water District	San Luis and Delta Mendota Water Authority
Task 1	$30,000	$168,200	$30,000	
Task 2	$30,000	$685,000		$35,000
Task 3	$40,000	$249,000		$35,000
Total	$100,000	$1,102,200	$30,000	$70,000

Table 2. Budget for project broken down by organization.

b. Schedule and Milestones

The project will take place over a two year period. All of the tasks will be initiated at the on-set of the project. In particular, the technology transfer efforts described in Task 3 will begin immediately to establish a dialogue between all members of the project team and to ensure the ongoing relevance and practical value of the other tasks. The following schedule assumes that funding will become available in the autumn of 1997. If funding is delayed considerably the schedule may shift due to the importance of seasonal factors in data collection. Table 3 lists major project milestones and completion dates.

c. Third Party Impacts

No third party impacts have been identified.

Task	Milestone	Completion Date
Task 1.	Final report on identification and measurement of unknown or unquantified sources of selenium in the Grasslands.	December 30, 1999
1a.	Assemble and evaluate existing data.	December 30, 1997
1b.	Obtain measurements to locate and verify potential sources of selenium entering the Grassland Water District.	November 30, 1999
1c.	Design and implement a first-response plan to measure the amount of selenium entering and flowing through the Grasslands Basin during flood or heavy rainfall events.	June 30, 1999
Task 2.	Final report on quantification of losses or additions of selenium associated with conveyance and storage of drainwater.	December 30, 1999
2a.	Quantify losses or additions of selenium that occur while drainwater is transported through the drainage canals, the San Luis Drain, and Mud Slough.	September 30, 1999
2b.	Quantify losses/additions of selenium associated with surface storage of drainwater.	September 30, 1999
2c.	Quantify losses/additions of selenium associated with in-field storage of drainwater.	September 30, 1999
Task 3.	Develop an on-line set of tools and a catalogue of options for reducing selenium in drainwater. Provide on-farm workshops, technical assistance, demonstrations and case studies to facilitate technology transfer.	December 30, 1999
3a.	Assist the district drainage managers in developing tools and a catalog of practical on-farm and district drainwater management options that are helpful in reducing selenium loads in drainwater.	September 30, 1999
3b.	Provide technical assistance in the implementation and evaluation of new or improved drainwater management options to reduce selenium levels in drainwater.	December 30, 1999

Table 3. Tasks, milestones and deliverables for the project.

V. QUALIFICATIONS

The team submitting this proposal has extensive practical field and research experience working on agricultural drainage and selenium related issues in the San Joaquin Valley and San Francisco Bay. Moreover, team members hold positions of authority within the key agencies and entities that can take action based on the findings of this project. The close cooperation among the Water District, Drainage Districts and the USBR represented by the collaborative nature of this proposal is indicative of the willingness of these parties to work together to find solutions to these challenging issues. Key personnel are assembled from the U. S. Bureau of Reclamation, E. O. Lawrence Berkeley National Laboratory, the San Luis and Delta Mendota Water Authority, and the Grassland Water District. Together they have over 50 years of experience working on water supply, drainage and selenium problems in the Central Valley. If additional expertise is needed, such as that provided by scientists from the U. S. Geological Survey, the University of California, or the U. S. Fish and Wildlife Service, their services will be sought. Qualifications for key personnel are provided below.

Mike Delamore, who will be the Project Manager, is currently the Chief of the USBR's San Joaquin Drainage Division. He earned his B.S. degree in wildlife ecology from Humboldt State University in 1977. He attended graduate school at Humboldt while conducting research on nesting prairie falcons at the Snake River Birds of Prey Area through the University of Idaho, Moscow and on the northern spotted owl for the U.S. Forest Service on the Six Rivers National Forest. He accepted a position with the U.S. Bureau of Reclamation in Boulder City, Nevada in 1979 where he worked on various water resource investigations. He became Head of the Environmental Sciences Branch in 1985, involved primarily in fishing and limnology studies on Lakes Mead and Mojave, salinity control investigations in Las Vegas Wash and vegetation management on the lower Colorado River. He came to the USBR in Sacramento in 1987 and worked primarily on the Kesterson Cleanup Program. In 1989 he became Chief of the Drainage and Water Quality Branch responsible for all Reclamation's projects and activities with the agricultural drainage in the west side of the San Joaquin Valley.

Joseph McGahan, who will be the primary liaison to the Grasslands Area Drainers, is currently the Interim Drainage Coordinator for the San Luis and Delta Mendota Water Authority. He has spent 26 years working in the field of irrigation, drainage and municipal water supply engineering in California and Arizona. He received his B.S. degree from California State Polytechnic College in 1970 and his M.S. degree from California Institute of Technology in 1971. He is a member of the American Water Works Association, the American Society of Civil Engineers and the U.S. Committee on Irrigation Drainage. He has presented various papers and made presentations to groups nationwide regarding water quality non-point source issues.

Don Marciochi, who will be the primary liaison to the Grassland Water District, is the General Manager of the Grassland Water District. He has been employed by Grassland Water District since 1973 and has served as the District Manager since 1983. He leads the Districts' efforts to secure a firm water supply by active participation in the development of the refuge provisions of the CVPIA. Similarly, he was involved in bringing about implementation of projects to remove selenium contamination due to drainwater in the Districts water supply.

Sally Benson, who will lead the technical team from E. O. Lawrence Berkeley National Laboratory, is currently serves as the Earth Sciences Division Director. She earned her B.A. degree in geology from Barnard College in 1977 and her M.S. and Ph.D. from the University of California at Berkeley in Engineering Science in 1988. Since 1977 she has been employed as a staff scientist at E. O. Lawrence Berkeley National Laboratory and in 1993 was appointed as the Director of the Earth Sciences Division. She has published over 100 research papers on characterization and monitoring of groundwater systems, many of these related to selenium. She has over 14 years of experience conducting field experiments on selenium contamination problems in the Central Valley of California, the Carson Desert in Nevada and the San Francisco Bay. She led the multi-organization scientific team that provided technical support for the Kesterson Reservoir Cleanup and quantified many key aspects of the behavior of selenium in aquatic ecosystems and groundwater systems. She has published numerous articles on selenium transport in soils and

sediments, 10 of which have appeared in peer-reviewed journals. She is also a visiting Professor at Clemson University in South Carolina where she teaches and performs research on groundwater contamination at the Department of Energy's Savannah River Site. She is a member of the American Geophysical Union, the Society of Petroleum Engineers and the American Association for the Advancement of Science.

Tetsu Tokunaga, who will provide technical and scientific support for the project, received his Ph. D. in Soil Science at the University of California, Berkeley, in 1986. He has 11 years of experience conducting field and laboratory research on selenium-contaminated wetlands and soils. Most of his field and laboratory studies have focused on trace element (Se, As, B) and salt transfers between surface waters and sediments of Kesterson Reservoir evaporation ponds and ephemeral pools, and playas in Stillwater (Nevada). In 1987, he identified the process of Se transfers from sediments into surface waters as an important environmental concern in ephemeral pools, and continues to be actively involved in ephemeral pool field monitoring and laboratory studies. He demonstrated the usefulness of synchrotron X-ray methods (X-ray absorption near-edge structure spectroscopy and the X-ray microprobe) in Se speciation in sediments and biological samples, and in understanding Se transport at the surface water-sediment interface. He has served on thesis committees and provided advise to graduate students involved in selenium and wetlands research (U.C. Berkeley, U.C. Davis, Stanford University, San Jose State University). He has published 11 peer-reviewed journal papers concerning Se in the environment. He also has expertise in-sediment pore water sampling and hydraulic potential measurements. He is a member of the Soil Science Society of America, American Chemical Society, American Geophysical Union, and Society of Wetland Scientists.

Peter Zawislanksi, who will provide technical and scientific support for the project, is a Staff Research Associate in the Earth Sciences Division of Lawrence Berkeley National Laboratory. He began working on selenium transport in soils in 1988, when he worked on issues of selenium redistribution in contaminated semi-arid soils of Kesterson Reservoir. His work showed that large fluxes of the toxic trace element can be expected as a result of evaporative water fluxes at the soil surface. He has worked on a number of soil chemistry and soil physics problems, including the continuation of work on Kesterson Reservoir soils, leading to a better understanding of selenium reduction and oxidation kinetics under varying environmental conditions. He was also the principal investigator on a multi-institutional 5-year bioremediation project aimed at dissipating soil-selenium via microbial volatilization. Within the last three years, he has directed a multidisciplinary field and laboratory research program on the cycling of selenium in the San Francisco Estuary, with a specific focus on fluxes of selenium, both dissolved and particulate, into and out of wetland sediments. This work has resulted in the understanding that sediment-water interface processes are very important with respect to selenium availability to biota and that sediments represent a long-term source of selenium to the benthic community. Peter has published numerous articles on selenium transport in soils, 3 of which are published in peer-reviewed journals.

Nigel Quinn, who will provide technical and scientific support for the project, is a staff scientist at E. O. Lawrence Berkeley National Laboratory. He received a Bsc (Hons) in irrigation engineering and hydrology from the Cranfield Institute of Technology in England and spent the early part of his career as an irrigation engineer for Tate and Lyle Inc. designing and troubleshooting irrigation systems in England and in Africa. He left England for Iowa in 1978 where he taught agricultural water management and surveying courses for three years, earning an MS in Agricultural and Civil Engineering and conducting research in soil erosion under crop canopy. In 1981 he took a position at Cornell University where he worked on various projects ranging from earthworm vermicomposting, pesticide model development and water supply and sanitation policy in developing countries, co-taught classes in surveying and computer programming and earned a Ph.D. in water resources systems engineering in 1987. He then joined the San Joaquin Valley Drainage Program where he developed groundwater and drainage models to support the Drainage Program's planning effort. He continues to work on Central Valley related issues, dividing his time between monitoring efforts in support of the Grasslands Bypass Channel Project, development of real-time forecasting tools for the San Joaquin River and selenium fate and transport re-

search projects. Nigel is the author of over 50 publications and reports on various aspects of water resources and drainage engineering.

A partial list of the most relevant publications prepared by the technical team is provided below.

Benson, S. M., in press, Influence of Nitrate on the Mobility and Reduction Kinetics of Selenium in Groundwater Systems, in Environmental Chemistry of Selenium, W.T. Frankenberger and R.A. Engberg, editors, Marcel Dekker, New York.

Benson, S.M., A.F. White, S. Halfman, S. Flexser, and M. Alavi. 1991. Groundwater contamination at Kesterson Reservoir, California 1. Hydrogeologic setting and conservative solute transport. Water Resour. Res. 27:1071-1084.

Benson, S.M., M. Delamore, and S. Hoffman. 1990. Kesterson Crisis: Sorting out the facts. In S.C. Harris (ed.) Irrigation and Drainage Proceedings of the 1990 National Conference. American Society of Civil Engineers. New York.

Frankenberger, W.T., Jr., and S.M. Benson, (eds.). 1994. Selenium in the Environment. Marcel Dekker, Inc. New York.

Long, R.H.B., S.M. Benson, T.K. Tokunaga, and A. Yee. 1990. Selenium immobilization in a pond sediment at Kesterson Reservoir. J. Environ. Qual. 19:302-311.

Poister, D., and T.K. Tokunaga. 1992. Selenium in Kesterson Reservoir ephemeral pools formed by groundwater rise: II. Laboratory experiments. J. Environ. Qual. 21:252-258.

Sutton, S.R., S. Bajt, D. Schulze, and T. Tokunaga. 1994. Oxidation state mapping using x-ray absorption near edge structure with synchrotron microbeams. Abstract presented at Am. Geophys. Union, Fall 1994 Meeting, San Francisco, CA.

Tokunaga, T.K., I.J. Pickering, and G.E. Brown, Jr. 1996. X-ray absorption spectroscopy studies of selenium transformations in ponded sediments. Soil Sci. Soc. Am. J. 60:785-790.

Tokunaga, T.K., S.R. Sutton, and S. Bajt. 1994b. Mapping of selenium concentrations in soil aggregates with synchrotron x-ray fluorescence microprobe. Soil Sci. 158:421-434.

Tokunaga, T.K, P.T. Zawislanski, P.W. Johannis, S. Benson, and D.S. Lipton. 1994. Field investigations of selenium speciation, transformation, and transport in soils from Kesterson Reservoir and Lahontan Valley. In, Selenium in the Environment. W.T. Frankenberger and S. Benson, eds. Marcel Dekker. New York. pp. 119-138.

Tokunaga, T.K., and S.M. Benson. 1992. Selenium in Kesterson Reservoir ephemeral pools formed by groundwater rise: 1. Field studies. J. Environ. Qual. 21:246-251.

Tokunaga, T.K., D.S. Lipton, S.M. Benson, A.Y. Yee, J.M. Oldfather, E.C. Duckart, P.W. Johannis, and K.H. Halvorsen. 1991. Soil selenium fractionation, depth profiles and time trends in a vegetated site at Kesterson Reservoir. Water, Air, and Soil Pollut. 57-58:31-41.

White, A.F., S.M. Benson, A.W. Yee, H.A. Wollenberg, and S. Flexser. 1991. Groundwater contamination at Kesterson Reservoir, California, Part 2. Geochemical parameters influencing selenium mobility. Water Resour. Res. 27:1085-1098.

Zawislanski, P.T., T.K. Tokunaga, S.M. Benson, J.M. Oldfather, and T.N. Narasimhan. 1992. Bare soil evaporation and solute movement of selenium in contaminated soils at Kesterson Reservoir. J. Environ. Qual. 21:447-457.

Zawislanski, P.T., and A.B. Crawley. 1997. Selenium cylcing study in the San Francisco Bay: A partnership involving federal and state government and industry. SPE Paper 37885. SPE/EPA 1997 Exploration and Production Environmental Conference, Dallas TX.

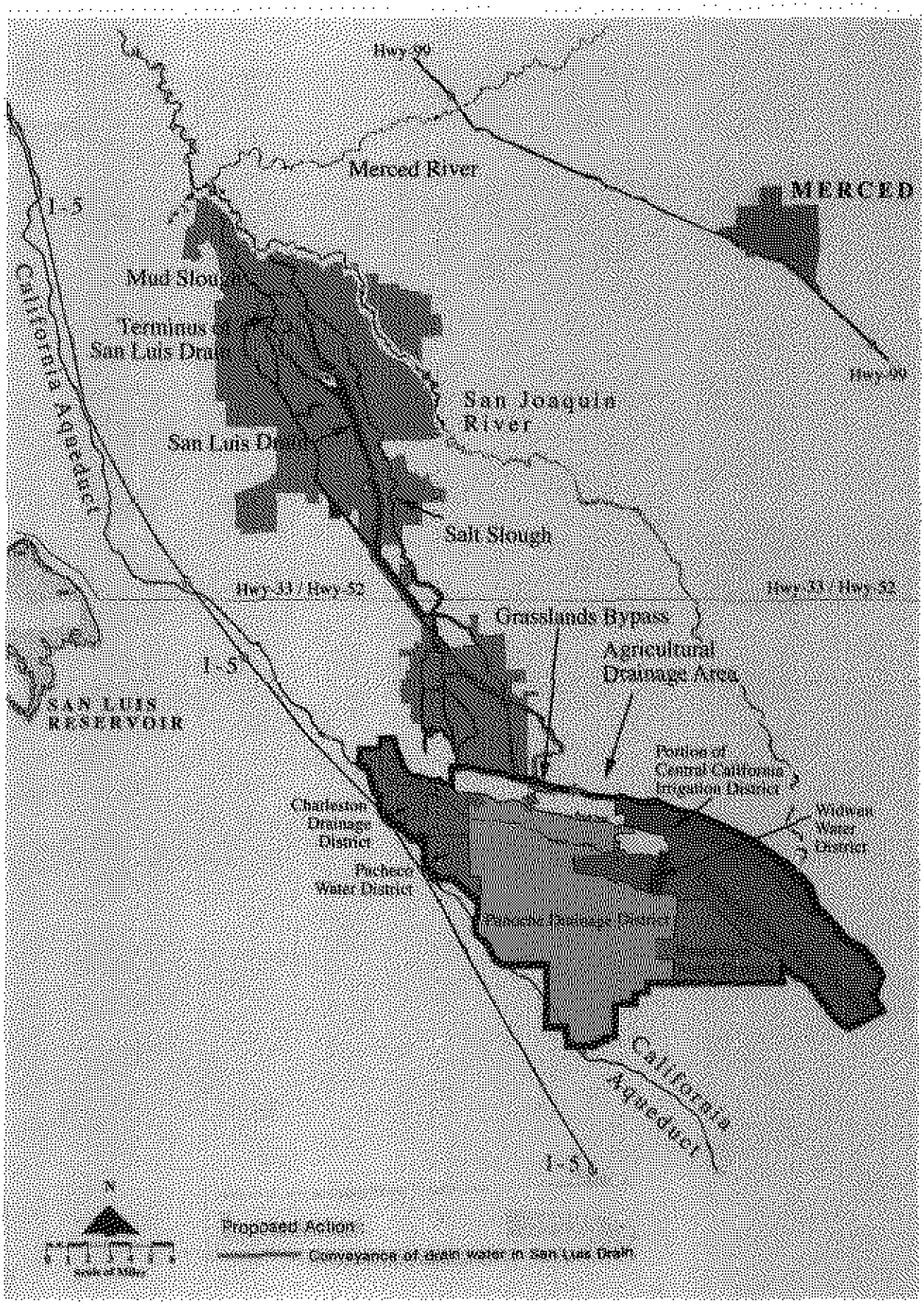
Zawislanski, P.T., and A.E. McGrath. 1997. Biogeochemistry of selenium in estuarine sediments of the San Francisco Bay: II. Distribution and fractionation. Abstract, Fourth International Conference on the Biogeochemistry of Trace Elements, Berkeley, CA.

Zawislanski, P.T., A.E. McGrath, and E. Gabet. 1997. Biogeochemistry of selenium in estuarine sediments of the San Francisco Bay: III. Sedimentation dynamics and selenium cycling. Abstract, Fourth International Conference on the Biogeochemistry of Trace Elements, Berkeley, CA.

Zawislanski, P.T., and A.E. McGrath, in press. Selenium cycling in estuarine wetlands: Overview and new results from the San Francisco Bay, in, Environmental Chemistry of Selenium, W.T. Frankenberger and R.A. Engberg, editors, Marcel Dekker, New York.

VI. COMPLIANCE WITH STANDARD TERMS AND CONDITIONS

The United States Bureau of Reclamation (USBR)will be the contracting authority on this proposal. Since the USBR is a federal agency no forms are required at this time as per Table D-1 (page 37) in the CALFED request for proposals.



Map 1a. Map showing the project location.

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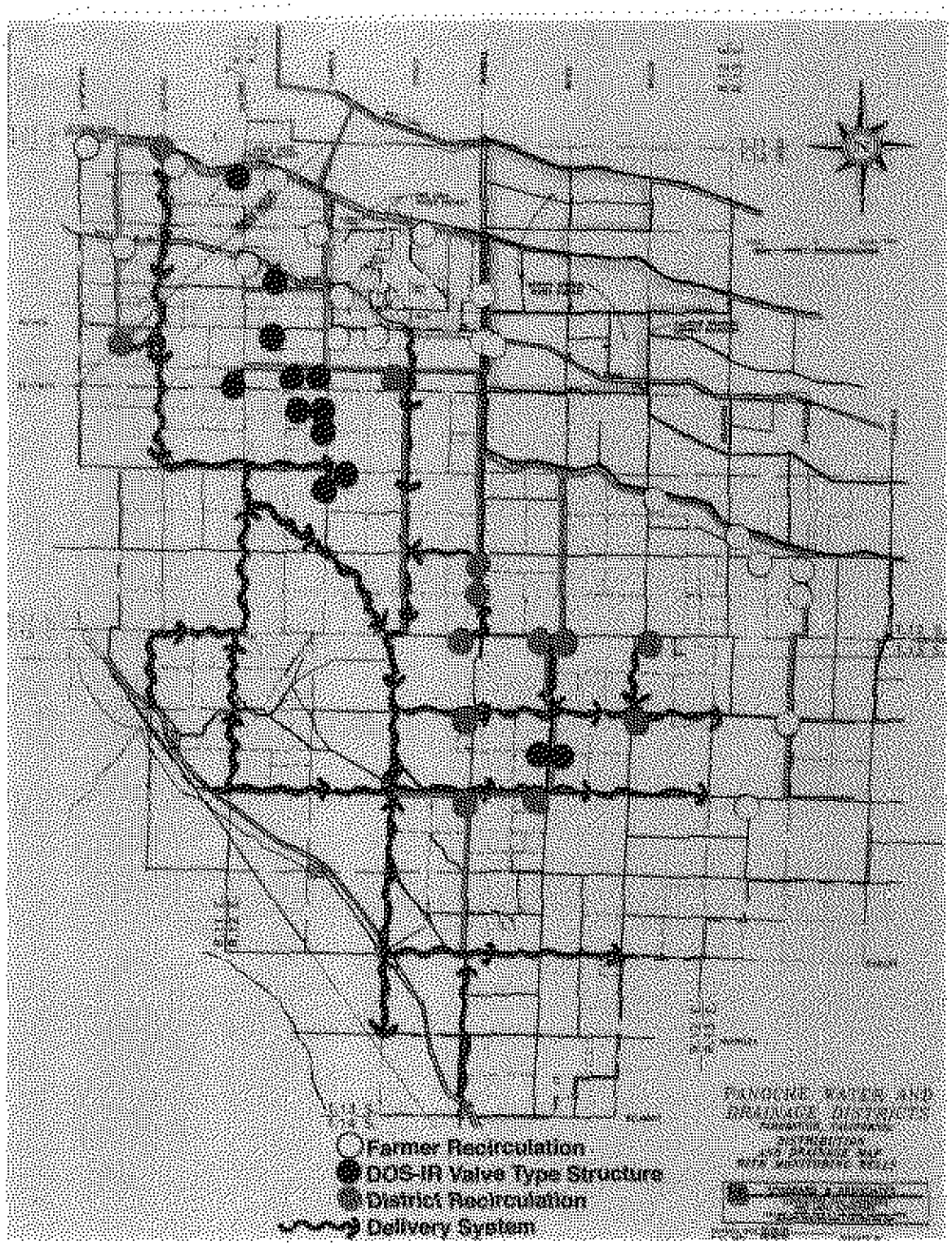

Map 1b.. Map showing location of on-farm and district structures for drain water management in the Grasslands.